"Sustainable Energy Solutions: Biodiesel Blends from Bitterwood Oil for Engine Efficiency and Emission Reduction"

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Abstract:- The growing industrialization and motorization worldwide have significantly increased the demand for petroleum-based fuels. However, these fuels are derived from limited reserves, leading to challenges for countries lacking these resources, especially due to the need for importing crude oil. This strains energy security and foreign exchange reserves. Therefore, it becomes imperative to explore alternative fuels that can be produced regionally, such as alcohol, biodiesel, and vegetable oils. Biodiesel is a fatty acid alkyl ester, a renewable, biodegradable, and non-toxic fuel that can be derived from both edible and non-edible oils through a process called transesterification. In India, one of the commonly used non-edible biodiesels is bitterwood oil methyl ester (BOME). In the present investigation, bitterwood oil-based methyl ester (biodiesel) is produced using a mixture of sodium hydroxide and Methonal, a mixed base catalyst, through the transesterification process. Direct injection, four-stroke single-cylinder petro-diesel engine using blends of bitterwood methyl esters with petro-diesel at different volume ratios (10%, 20%, 30%, and 100%). In this process, a comprehensive study of performance and emission tests was conducted, aiming to understand how biodiesel blends, particularly those derived from bitterwood oil, perform in internal combustion engines concerning efficiency and emissions. Such research is crucial for the development and adoption of sustainable and environmentally friendly fuel alternatives, especially in regions facing energy and foreign exchange challenges due to petroleum dependence.

Keywords: *Biodiesel, Bitterwood Seed, Transesterification.*

1. Introduction

It emphasizes the dominance of fossil fuels as the primary energy source, driven by increasing industrialization and modernization. However, it also points out the challenges associated with this reliance, including the burden on economies of developing countries due to the need for importing fossil fuels, limited reserves, past energy crises, and environmental concerns such as carbon dioxide emissions and pollution. In response to these challenges, there is a growing need to explore alternatives to conventional liquid fuels (7)

India is singled out as having the potential to become a leading producer of biodiesel, which can be derived from non-edible oils such as jatropha curcas, honge, neem, mahua, bitterwood seed, cottonseed, and tobacco seed. This indicates the country's abundant resources and potential to contribute significantly to the production of renewable energy sources (7)

Biodiesel is a fuel akin to diesel, made from organic materials, suitable for direct use in internal combustion engines. It boasts biodegradability and non-toxicity, along with emitting lower levels of pollutants. Additionally, it improves engine longevity by offering enhanced lubrication, thereby decreasing premature wear on engine parts. (19)

2. Methodology

Step by step procedure of production of bitterwood seed biodiesel is given below

2.1 Extraction of seed oil

The extraction of oil from bitterwood seed is done by using a method called mechanical expeller. Extraction requires passing the seeds through a screw crusher, generally called expeller, i.e. Screw Oil Expeller. The oil is then filtered to make it clean enough for processing.

Fig.1: Deshelling of seeds

Fig 2: Oil expeller

Fig 3: bitterwood seed oil

2.2 Determination of FFA content of seed oil

The fatty acid is a Carboxylic acid, with a long aliphatic chain, which is either saturated or unsaturated. The seed oil sample of 1 ml is taken in a flask and 10 ml of iso-propyl alcohol is added (seed oil : iso-propyl alcohol is always maintained in the ratio of 1:10). 2 drops of Phenolphthalein indicator is added to the mixture of seed oil and iso-propyl alcohol and thoroughly mixed. This mixture is titrated against a standard solution of Sodium Hydroxide (NaOH). On the completion of titration, the colour of the solution changes from colourless to light pink. The amount of NaOH consumed is noted to calculate the Free Fatty Acid (FFA) content of the scum. The FFA content of the scum is calculated by the following formula

$$\text{FFA Content} = \frac{(28.2 * \text{Normality of NaOH} * \text{ml of NaOH consumed})}{\text{Weight of the oil}}$$

If the FFA content is below 4, a single stage of production of biodiesel can be carried out i.e the Trans-esterification. If the FFA content is greater than 4, a two stage production has to be carried out for the production of biodiesel, i.e acid-esterification to reduce to FFA content below 4 and trans-esterification.

2.3 Acid Esterification

Acid-esterification is the general name given to the chemical reaction in which two reactants (typically an alcohol and an acid) form an ester as the reaction product.

Fig 4: Experimental setup

1 litre of seed oil is heated to about 60^0 on a hot plate magnetic stirrer and it is transferred to a clean and dry three necked flask.80 ml of Methanol and 2.5 ml of H_2SO_4 is added and stirred at a constant speed of 800 rpm for 2 hours.

After the completion of reaction, the solution is allowed to cool down and then transferred to a separatory funnel and allowed to cool down for 12 hours. The formation of layers takes place, in which the top layer formed is the processed oil, which is brown in colour and the lower layer is the Free Fatty Acid which has to be drained out, separating it from the supernatant processed seed oil. The processed seed oil is then tested for Free Fatty Acid. The resulting FFA was found to be again more than 4, hence, the seed oil was again used to carry out the acid esterification process. Again, the processed seed oil is tested for Free Fatty Acid. Since resulting FFA was found to be 1 (less than 4), the seed oil was used to carry out the trans-esterification process.

Table.1: weight of NaOH for transesterification

FFA	NaOH (gm)
0	3.8
1	4.2
2	5.8
3	6.9
4	7.3

2.4 Transesterification

Transesterification is the process of exchanging the alkali group of an ester compound by another alcohol. These reactions are often catalyzed by the addition of an acid or a base.

The processed scum is transferred to a three necked flask and is kept on a hot plate magnetic stirrer, heated to 60^0. After the temperature reaches to 60◦, 120 ml of Methanol and 4 gm of NaOH are mixed in a beaker and then added to the three necked flask, which is kept in a constant stirring condition at a speed of 800 rpm. The reaction is allowed to proceed for duration of 2 hours. After the reaction is completed, the solution is allowed to cool down.

Upon cooling, it is then transferred to a separatory funnel, where it is allowed to settle down for a duration of 12 hours. The separation of layers takes place, where the upper layer is the biodiesel which appears brownish in colour. The lower layer is the Glycerine, an unwanted product that is separated from the biodiesel, by draining it into a beaker.

Fig 5: Separation layer of biodiesel and Glycerine

The biodiesel is then washed with warm water (60◦) in order to remove the methanol present in the biodiesel. The biodiesel has to be washed till the water used does not change colour after the wash. The biodiesel is then heated to a temperature of 100^0 to remove any traces of water content present in it. The biodiesel is then stored for further tests to be conducted on it.

Fig 6: water washing

Fig 7: Biodiesel & Glycerin

3. Results and Discussion

3.1 Properties of Bitterwood Seed Biodiesel

Different properties of biodiesel like Density, Kinematic Viscosity and Calorific value were tested using hydrometer, viscometer and bomb calorimeter respectively. Bitterwood seed biodiesel was blended with conventional diesel in the following proportions: -

B10: 10% Biodiesel + 90% Diesel

B20: 20% Biodiesel + 80% Diesel

B30: 30% Biodiesel + 70% Diesel

Table 2: Properties of Biodiesel

properties	Density (kg/m^3)	Viscosity (cst)	calorific value (kj/kg)
Diesel	830	3.28	38315.06
B10	840	3.21	37323.80
B20	845	3.78	36720.30
B30	860	3.96	36668.01
B100	885	4.25	32050.12

3.1.1 Variation of Density for Different Biodiesel-Diesel Blends

Density of Biodiesel depends upon molecular weight. Since the density of bitterwood seed biodiesel is more than conventional diesel fuel, the density of different blends increases with the increase in biodiesel percentage and same can be observed in table 2. Bitterwood seed Biodiesel has maximum density of 885 kg/m^3. Among blends B10 has density close to Diesel value i.e. 840 kg/m3.

3.1.2 Variation of Kinematic Viscosity for Different Biodiesel-Diesel Blends

Viscosity is one of the most significant properties of biodiesel since it plays a vital role in fuel injection process of diesel engine. If the viscosity is high it affects atomization process because of which effective mixing of fuel with air will not takes place and it in turn causes incomplete combustion. Viscosity will be high for those oils having longer chain length of fatty acid and is less for those oils having more amount of unsaturated fatty acid. From table 2, it can be observed that bitterwood seed Biodiesel has highest viscosity of 4.25 cSt. Among blends B10 has viscosity nearer to diesel value i.e. 3.21 cSt.

3.1.3 Variation of Calorific Value for Different Biodiesel-Diesel Blends

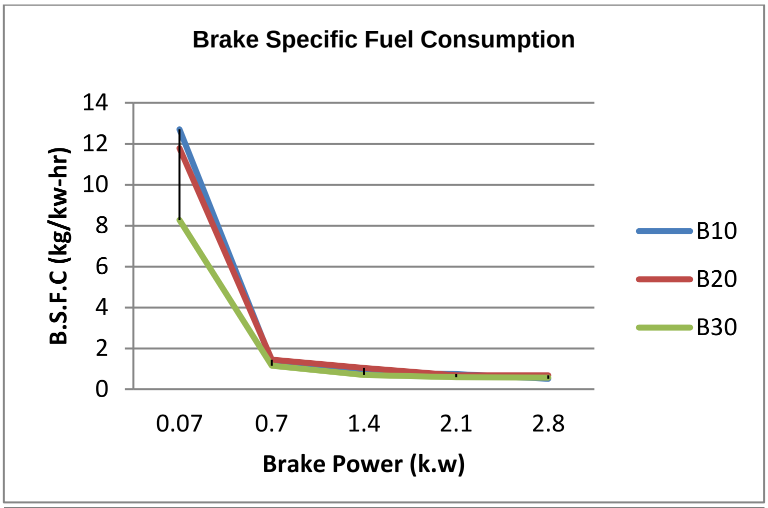
Calorific value of fuel is one of the important parameters that determines efficiency of an engine. Higher the calorific value of a fuel, larger amount of heat will be released which increases the efficiency of the engine. From table 2, it can be observed that as biodiesel percentage in blends increases there is a decrease in calorific value. It is because of the reason that since Biodiesel is an oxygenated fuel; its calorific value is less compared to diesel. Diesel has a highest calorific value 38315.06kJ/kg and among blends B10 has calorific value nearer to diesel value 37323.80 kJ/kg.

3.2 Performance Evaluation

In IC engine, the thermal energy is released by burning the fuel in the engine cylinder. The combustion of fuel in IC engine is quite fast but the time needed to get a proper air/fuel mixture depends mainly on the nature of fuel and the method of its introduction into the combustion chamber.

3.2.1 Brake Specific Fuel Consumption (B.S.F.C)

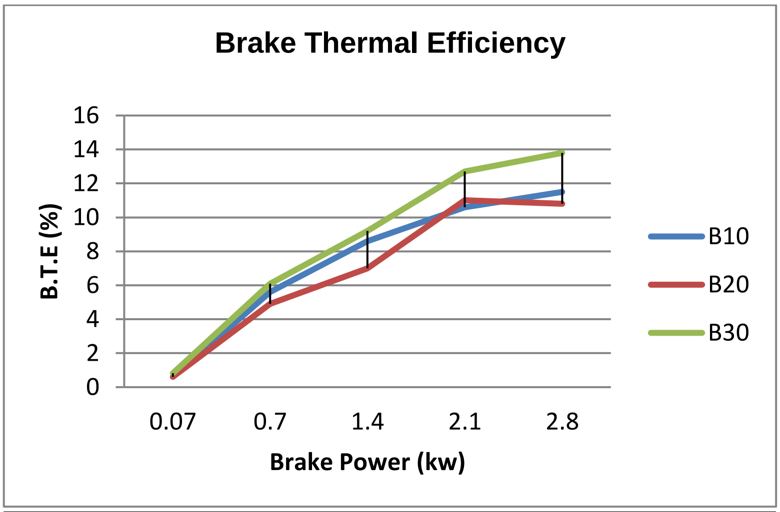
Brake Specific Fuel Consumption (B.S.F.C.) is the fuel consumed by the engine per unit of power output or produced. It is desirable to obtain a lower value of BSFC meaning that the engine used less fuel to produce the same amount of work.



For fuel tested, decrease in B.S.F.C. was found with increase in brake power. It can be seen from this graph that as Brake Power increases, B.S.F.C. decreases to minimum at full load condition. By observing related results at full load engine condition, the value of B.S.F.C. for B10 blend is minimum.

3.2.2 Brake Thermal Efficiency

Brake Thermal Efficiency is the ratio of the power output of the engine to the rate of heat liberated by the fuel during the combustion.



It is observed that the brake thermal efficiency is low at low values of BP and increases with increase of BP for all blends of fuel. For a blend of 30% the brake thermal efficiency is high at low BP values when compared with other blends of fuel. Hence at the blend of 30%, the performance of the engine is good.

3.3 Emission Characteristics

Fuel	Exhaust Emission (ppm)			
	CO	HC	SO_2	NO_2
DIESEL	0.069	11	6	579
B10	0.049	12	8	801
B20	0.070	17	4	797
B30	0.012	8	1	827

The above table shows that all emissions with biodiesel are lower than diesel except NO_2. NO_2 emissions will increase when using biodiesel. This increase is mainly due to higher oxygen content for biodiesel. The higher of NO_2 emission could be reduced either by the use of catalytic converter.

The above analysis of biodiesel shows that the reduction in CO emission is about 19% with B10 and 76% with B30 use on per litre combustion basis. CO emissions reduce when using biodiesel due to the higher oxygen content and the lower carbon to hydrogen ratio in biodiesel compared to diesel.

4. Conclusion

The bitterwood seed oil was successfully extracted from the seeds. The oil thus extracted was made to undergo the transesterification process and conditioned. Bio-diesel properties are then compared with neat diesel. The blend B10 properties were close to diesel properties. Calorific value of B10 is more compared to B20 and B30. Reduced viscosity which in turn increases the fuel automization resulting in good combustion. From the performance evaluation, it is observed that the performance of C.I engine has increased by using blended biodiesel in comparison with pure diesel. From this study it is observed that the blended biodiesel can be used as an alternate fuel for the C.I engine without any engine modification. It is inferred, from the results that the brake thermal efficiency is higher for B30 and less fuel consumption for B10.

From the emission characteristics, it is concluded that biodiesel and its blends as a fuel for diesel engine have better emission characteristics compared with diesel as follows:

(1) CO emissions are less compared with diesel

(2) NO_2 emissions for biodiesel and blended fuel are slightly higher than that of diesel

(3) From this analysis it can be concluded that B30 gives better performance with reduced pollution.

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